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ABRASION-RESISTANT ALUMINUM ALLOY
[Taimamousei aruminiumu goukin]

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Specification

/1*

1. Title of the Invention

Abrasion-resistant aluminum alloy

2. Claims

(1) An abrasion-resistant aluminum alloy, characterized by the fact of containing 13 to 18% by weight of Si, 1 to 7% by weight of Cu, 3 to 7% by weight of Ni, 0.2 to 1.5% by weight of Mn, 1.0% weight or less of Mg, 1.5% weight or less of Fe, with the remainder substantially comprising aluminum.

(2) An abrasion-resistant aluminum alloy, characterized by the fact of containing 13 to 18% by weight of Si, 1 to 7% by weight of Cu, 3 to 7% by weight of Ni, 0.2 to 1.5% by weight of Mn, 1.0% by weight or less of Mg, 1.5% by weight or less of Fe, and at least one species selected from 0.001 to 0.3% by weight Ti, 0.001 to 0.1% by weight B, 0.001 to 0.2% by weight P, 0.001 to 0.1% by weight Sr, and 0.05 to 0.3% by weight Sb, with the remainder substantially comprising aluminum.

3. Detailed Explanation

[Technical Field of the Invention]

The present invention pertains to an aluminum alloy with superior abrasion resistance.

[Prior Art]

* Numbers in the margin indicate pagination in the foreign text.

Conventionally, AC8A alloy (JIS aluminum alloy caste material) or 390 alloy (hypereutectic Al-Si alloy) or the like have been used for friction materials in an internal combustion engine.

AC8A alloy is an aluminum alloy that contains approximately 1% by weight of Cu and Mg, 11 to 13% by weight of Si, and, in order to improve heat resistance, Ni ranging from 0.8 to 1.5% by weight.

Usually it is used after having been subjected to a heat treatment (T_6 or T_7). Because this aluminum alloy has less Si and Cu than 390 alloy, it is known to have high temperature strength because Ni, which has relatively high toughness, has been added. Nevertheless, there is a problem with the abrasion resistance of the mold release mode of the alloy, due to the small amount of Si and Cu added. Accordingly, it is generally difficult to utilize this alloy in diecast products that are used without a heat treatment being conducted. Another problem with this alloy is that alpha phase is often crystallized out in the solidification structure, so adhesion readily occurs during friction between adjacent Al alloys.

On the other hand, the abrasion resistance of 390 alloy is superior to that of AC8A alloy, because Si is added up to the hypereutectic region, therefore much primary crystalline phase is dispersed throughout the solidification structure. This advantage, /2
in combination with the advantage of a low coefficient of thermal expansion, allows it to be used in frictional parts such as shift forks and sliding contact parts of an engine, either in a casting

release mode or in a mode where a stabilization treatment has been conducted. Nevertheless, it is difficult to say that the abrasion characteristics are satisfactory for a linerless cylinder block material where a high degree of abrasion resistance is required. One factor here is that the alpha phase is frequent in solidified structure, as was the case for AC8A alloy, so seizing readily occurs during friction.

[Problems to be solved by the invention]

Therefore, in a case where 390 alloy is to be used as a liner material, such as a linerless cylinder block material, the abrasion resistance is improved by conducting a special etching treatment that etches the matrix and causes primary crystalline phase Si to float up. In order for 390 alloy to be used in a part that is subjected to this type of harsh abrasion condition, a special treatment is required, which presents the problem of increasing the number of steps in production. A further disadvantage is that, in a case that presumes the use of engine parts in a high-temperature environment, the high temperature strength of 390 alloy is lower than that of AC8A alloy.

[Means to solve the problems]

The object of the present invention is to offer an aluminum alloy that has high temperature strength and abrasion resistance greater than that of 390 alloy, in a mold-release condition, in order to solve the problems described earlier.

The aforementioned object is achieved by the present invention as described below.

Specifically, the present invention is an aluminum alloy that contains 13 to 18% by weight of Si, 1 to 7% by weight of Cu, 3 to 7% by weight of Ni, 0.2 to 1.5% by weight of Mn, 1.0% by weight or less of Mg, 1.5% by weight or less of Fe, and, as the occasion may require, at least one species selected from 0.01 to 0.3% by weight Ti, 0.001 to 0.1% by weight B, 0.001 to 0.2% by weight P, 0.001 to 0.1% by weight Sr, and 0.05 to 0.3% by weight Sb, with the remainder substantially comprising aluminum.

The invented aluminum alloy superior high-temperature strength and abrasion resistance, due to the fact that the aforementioned specific ranges for Si, Cu, Ni, Mn, Mg, and Fe are stipulated.

The present invention is explained in greater detail below.

First, the reasons for limiting the chemical composition of the invented aluminum alloy are explained.

(Si)

The addition of Si relates to deposition of eutectic Si, primary crystalline phase Si, to improving the strength, hardness, and abrasion resistance, and to lowering the coefficient of heat expansion. In a case where uniform distribution of Si granules is obtained, the effect conferred upon abrasion resistance is particularly great. Abrasion resistance is unsatisfactory at 13% by weight or less, because the amount of primary crystalline phase Si is

small; if 18% by weight is exceeded, liquidus temperature is elevated, and castability is reduced.

(Ni)

Ni forms Al-Ni system compounds and Al-Ni-Cu system compounds, improves strength, hardness, and abrasion resistance without a significant accompanying reduction in toughness, and is also effective in improving strength at high temperatures. The effect of Ni on high temperature strength is saturated at about 3% by weight, but if more than this is added the hardness and abrasion resistance are significantly improved, and there is also an advantage in lowering the coefficient of thermal expansion. [The specified range of] the invented alloy is attentive to this point, thus in contrast to a conventional alloy where Ni content is keep below 3% by weight due to alloy cost considerations and the saturation of the heat resistance effect, [in the present invention] hardness and abrasion resistance are improved by adding 3% by weight or more Ni. The abrasion resistance is unsatisfactory if Ni content is less than 3% by weight, but when Ni content exceeds 7%, the deposition of needle-like coarse compound increases and toughness is signficantly lowered. The solidification temperature range increases due to the elevation of liquidus temperature, and cracks easily form during diecasting.

(Cu)

Cu forms a 2-phase solid solution, and improves load-carrying capacity and hardness. Al-Ni system compounds and Al-Ni-Cu system

compounds are also formed, with an increase in high temperature strength and abrasion resistance. Hardness and abrasion resistance are insufficient at less than 1% by weight, and when 7% by weight is exceeded, segregation becomes dramatic with a decline in toughness unaccompanied by an improvement in strength. It also has a negative effect on castability.

(Mn)

Mn forms a good solid solution in an Al phase; in an Al-Mn 2-dimensional equilibrium diagram, the solid-solubility limit is approximately 1.8% by weight at the eutectic point (1.9%, 657°C). Hardness and strength are improved by the addition of Mn; when Si, Fe, Ni, and Cu, for example, are also present, Al-Mn-Si-Fe system compounds and Al-Ni-Cu-Mn-Fe system compounds, for example, are formed, improving not only the hardness and strength, but also abrasion resistance and high temperature strength. The effect is not observed when the content of Mn is less than 0.2% by weight, and castability and toughness are impaired when the content exceeds 1.5% by weight.

(Mg)

Mg partly forms a solid solution in alpha phase, the rest /3 crystallizes out as Mg_2Si or Al-Cu-Mn system compounds, and from these effects it improves strength and abrasion resistance. Nevertheless, when 1.0% by weight or more is added, the amount of crystallization of brittle compounds such as Mg_2Si, for example, increases, and

toughness is reduced, so it is necessary that the amount added be kept at 1.0% by weight or less.

(Fe)

Al-Fe-Si system compounds are formed when Fe content is 1.5% by weight or greater, which results in such phenomena as pronounced loss of ductility, and hard spots, so it is necessary to limit the content to 15% [sic] by weight or less.

[Microstructural elements and modification treatment elements]

Ti and B are publicly known to be elements that have an effect on the microstructure of crystal grains, so as to improve castability; Ti is added in a range of 0.001 to 0.3% by weight, and B is added in a range of 0.001 to 0.1% by weight; Ti may be added alone, or Ti and B may be added in combination.

P is publicly known as an element that has an effect on primary crystalline phase Si, an effect that is observed when the content ranges from 0.001 to 0.2% by weight.

Sr and Sb are added as the occasion may require, as elements for modification treatment of eutectic Si. These elements are effective for improving toughness, due to an effect on fine structure of a eutectic Si phase. A suitable content is 0.001 to 0.1% by weight of Sr and 0.05 to 0.3% by weight of Sb.

An aluminum alloy is disclosed in Tokkai Patent SHO 61-139636 that comprises 14 to 18% by weight Si, 0.4 to 2% by weight Fe, 4 to 6% by weight Cu, 4.5 to 10% by weight Ni, and 0.001 to 0.1% by weight

P, with the remainder being Al; this is described as having superior high temperature strength, and load-carrying capacity in particular. Although the experimental conditions are not necessarily the same as the conditions for the working examples of the present invention, nevertheless the alloy disclosed in the Official Gazette has a tensile strength (T. S.) at 500°F (227°C) of 20.7 Ksi (14.6 Kgf/mm^2) at S-505318, which cannot be said to be particularly superior in comparison to the invented alloy. Furthermore in the case of the disclosed alloy, [the Rockwell hardness] at 66-67 RB (HRB) is significantly inferior to that of the invented alloy. In the matter of abrasion resistance, the disclosed alloy is not necessarily satisfactory. The cause is thought to be that the alloy disclosed in the Official Gazette does not contain Mn, but in the present invention Mn is added within a specified range as described above, resulting in superior hardness and abrasion resistance.

[Working Examples]

The present invention is explained in greater detail below with reference to working examples.

Samples Nos. 1 through 11 are test samples, having the shape shown in Figure 1, that were prepared from alloy melts having the compositions shown in Table 1, using a 90-ton diecast machine, under conditions of casting temperature of 730 to 750°C, die temperature of 110 to 135°C, injection rate of 1.3 to 1.4 m/s, casting pressure of 760 kgf/cm^2, and chill time of 5 seconds. Sample No. 1G is a test

sample prepared by subjecting an alloy having Composition No. 1 to metal die casting (gravity) in a test sample shape of 10 x 30 x 50 mm dimensions.

The following tests were performed, using the aforementioned Samples Nos. 1 to 11 and No. 1G. The test findings are shown in Tables 2 to 4, and microphotographs of the metal structure of the solidification structure are shown in Figure 2.

(1) Tensile strength (room temperature)

A tensile strength test was performed on tensile test pieces (2) shown Figure 1, in a condition where Sample Nos. 1 to 11 had been released from casting. The tension rate (cross-head speed) at this time was 5 mm/min, and the gauge length for stretch measurement was 50 mm.

(2) High temperature tensile test

Tensile test pieces (2) shown in Figure 1 for Sample Nos. 1, 4, 10, and 11 were subjected to a tensile test in an atmosphere of 250°C, in a condition of cast releasing. The holding time was 60 minutes.

(3) Hardness test

The Rockwell hardness (HRB) in a casting release condition was measured, using Sample Nos. 1 to 11 of the flat test piece (1) shown in Figure 1.

[Translator's note: There is no (4)]

(5) Abrasion test

An abrasion test was conducted with an Ohkoshi Abrasion Tester, using the flat test piece (1) shown in Figure 1. The test conditions used were a final load of 18.9 kg, abrasion distance of 400 m, abrasion speed of 2.86 m/s, FC25 as counter material, and a moist environment using commercial motor oil (10-30W) as lubricant.

(6) Observation of solidification structure

The solidification structure of samples No. 1, No. 1G, No. 10 (390 alloy), and No. 11 (AC8A alloy) was observed under light microscope. The observation site was approximately 0.5 mm from the cast skin of flat test piece (1) shown in Figure 1. A 1% hydrofluoric acid solution was used for an etching treatment.

Table 1. Alloy Composition (other than Al) (% by weight) /4

a) 元素 / No.	Si	Cu	Ni	Mn	Mg	Fe	Ti	P	b) その他の元素	
1	17.82	4.92	5.60	0.50	0.21	0.23	0.09	0.03	B 0.002 Sb0.11	本発明合金 c)
2	16.80	2.71	5.54	0.52	0.01	0.21	0.11	0.03	B 0.003 Sb0.002	〃
3	14.71	5.51	5.49	0.33	0.01	0.37	—	—	—	〃
4	18.67	2.02	6.04	0.31	0.30	0.38	0.10	0.04	—	〃
5	12.52	2.10	3.12	0.01	0.53	0.34	0.10	—	—	比較合金 d)
6	19.21	3.98	2.01	0.53	0.51	0.35	—	0.03	—	〃
7	17.02	3.49	2.02	0.01	0.32	0.35	—	0.03	—	〃
8	17.11	3.14	8.12△	0.49	0.01	0.37	—	0.03	—	〃
9	17.20	2.81	5.69	1.97	0.01	0.21	0.09	0.03	—	〃
10	16~18	4.0~5.0	<0.1	<0.5	<0.45~0.65	<1.3	—	0.03	Zn<1.5 Sr<0.3	参考合金 (390合金) e)
11	11.0~13.0	0.8~1.3	0.8~1.5	<0.15	0.7~1.3	0.8~1.5	<0.2	—		参考合金 (AC8A合金) f)

Key:
a) Element
b) Other elements
c) Invented alloy
d) Comparative alloy
e) Reference alloy (390 alloy)
f) Reference alloy (AC8A alloy)

Table 2. Tensile strength, load-carrying capacity and elongation

a) 性質 No.	b) 引張強さ (Kgf/mm²)	c) 0.2%耐力 (Kgf/mm²)	d) 伸び (%)	e) 硬さ (HRB)	f) 備考
1	20.5	19.8	0.5	81	本発明合金 g)
2	20.1	18.1	0.6	79	〃
3	21.7	20.4	0.6	79	〃
4	23.6	20.6	0.6	79	〃
5	22.8	17.9	1.0	70	比較合金 h)
6	23.9	22.6	0.4	75	〃
7	20.5	19.3	0.6	73	〃
8	30.1	20.6	0.2	85	〃
9	20.4	20.6	0.4	83	〃
10	21.3	20.5	0.6	76	参考合金 (390合金) i)
11	27.1	19.3	0.7	71	参考合金 (AC8A合金) j)

Key:
a) Property
b) Tensile strength (Kgf/mm^2)
c) 0.2% load-carrying capacity (Kgf/mm^2)
d) Ductility (%)
e) Hardness (HRB)
f) Remarks
g) Invented alloy
h) Comparative alloy
i) Reference alloy (390 alloy)
j) Reference alloy (AC8A alloy)

Table 3. The abrasion resistance

NO.	a 比摩耗量 $\times 10^{-7}\ mm^2/kg$	b 備考
1	2.41	本発明合金 c
18	2.84	d 〃 (グラビティ鋳造)
2	3.41	本発明合金 e
3	3.61	〃
4	3.52	〃
5	11.39	比較合金 f
7	8.67	〃
10	4.52	参考合金 (390合金) g
11	11.51	〃 (AC8A 合金) h

Key:
a) Specific wear rate
b) Remarks
c) Invented alloy
d) " (Gravity cast)
e) Invented alloy
f) Comparative alloy
g) Reference alloy (390 alloy)
h) Reference alloy (AC8A alloy)

Table 4. Tensile strength and elongation (at 250°C)

NO.	a 引張強さ (Kgf/mm^2)	b 伸び (%)	備考 c
1	20.6	0.6	d 本発明合金
4	21.1	0.7	〃
10	18.3	0.7	参考合金 (390合金) e
11	21.7	0.7	〃 (AC8A 合金) f

Key:
a) Tensile strength (Kgf/mm^2)
b) Ductility (%)
c) Remarks
d) Invented alloy
e) Reference alloy (390 alloy)
f) Reference alloy (AC8A alloy)

As shown in Table 2, the tensile strength, load-carrying capacity, and elongation of the invented alloy are on the same order as 390 alloy, and the hardness, being 79 to 81 (HRB) is higher than the reference alloys, 390 alloy and AC8A alloy.

The hardness of Samples No. 5 and No. 7 was low because the amount of Si or Ni added, respectively, was small. In contrast, the amount of Si [and/or] Ni added in Samples No. 6 and No. 8 was too great, so the elongation value was extremely low, thus cracks readily occur during die-casting.

As shown in Table 3, the abrasion resistance of the invented alloy, for any of the alloys, was superior to that of 390 alloy and AC8A alloy. In Table 3, Sample No. 1G is a metal mold (gravity) cast form of No. 1, but the specific abrasion was not greatly different from that of the diecast Sample No. 1, demonstrating that the invented alloy makes it possible to obtain a degree of abrasion resistance in a metal mold (gravity) cast form, similar to that of die casting.

Due to the inadequate amounts of Si or Ni added in comparative alloy Samples No. 5 and No. 7, abrasion resistance is inferior to the invented alloy and to 390 alloy.

Table 4 shows the tensile strength and elongation at 250°C. The tensile strength of the invented alloy (Samples No. 1 and No. 4) /5 is higher than 390 alloy (No. 10), and equivalent to AC8A alloy (No. 11).

Microscopic photographs of the alloy structures, for both the solidification structure of the invented alloy and the reference alloys, are shown in Figure 2. The alpha phase crystal deposition amount of the solidification structure of the invented alloy is much less than that of 390 alloy and AC8A alloy, with granular primary crystalline phase Si and fine eutectic phase embedded in the structure. (Thus it has superior abrasion resistance.) A fine eutectic phase and initial crystal Si similar to that of Sample No. 1 has also formed in the structure of Sample No. 1G, which has been subjected to metal mold casting (gravity).

[Effect of the Invention]

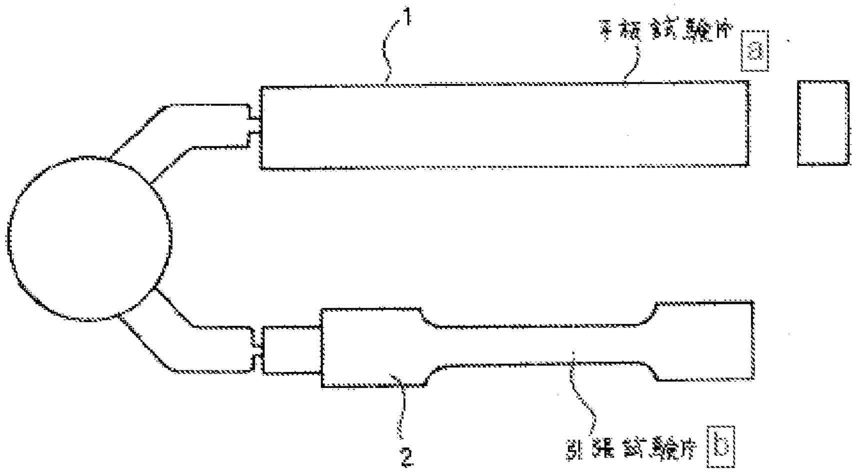
As explained above, the invented alloy, in any [of its modes] does not produce the problem of seizing during friction because alpha phase deposition is low. Accordingly, a significant effect is offered to the industrial field because, the abrasion resistance and high temperature strength being superior to 390 alloy in a mold-release condition, it is suitable for use as an engine part such as a cylinder block or piston, for example, and can be expected to have a wide range of other applications for other friction members.

4. Brief Explanation of the Drawings

Figure 1 is a plan view showing a test piece used for testing working examples of the present invention and comparative examples.

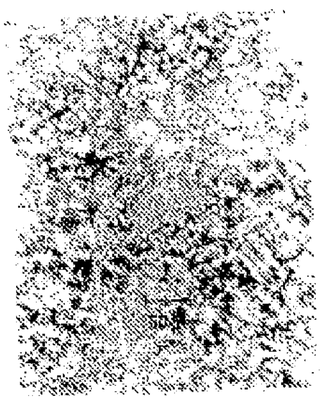
Figure 2 is a set a microscopic photographs showing the metallic composition of samples of reference alloys and the invented alloy obtained in the working examples.

Figure 1

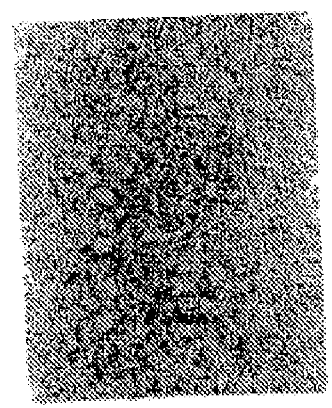


Key: a) Flat sheet test piece; b) Tensile test piece

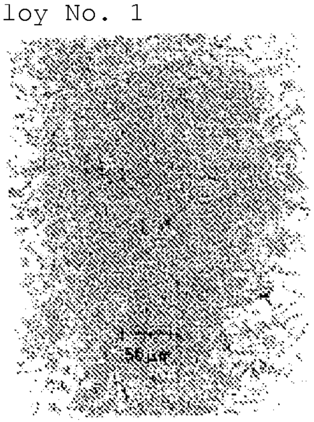
Figure 2 /6



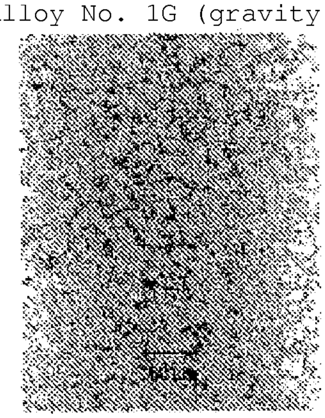
Invented Alloy No. 1



Invented Alloy No. 1G (gravity cast)



Reference Alloy No. 10 (390 Alloy)



Reference Alloy No. 11 (AC8A Alloy)